Efficient High Frequency Checkpointing for Recovery and Debugging

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Computers and their software play an ever increasing role in our daily life—software runs on our computers, phones, TVs and around our wrists in the form of smart watches. While one can argue that software has improved our quality of life in many ways, it is also plagued by a problem, which is as old as software itself: Reliable software is hard to build. “Have you tried turning it off and on again”, has become our pop-culture’s iconic manifestation of this problem. Checkpointing is an important technique that has many applications inside the reliability domain, such as automated error recovery and debugging. An integral part of checkpointing is taking a snapshot of a process’ memory, also known as memory checkpointing, which is the main subject of this thesis.

In particular this thesis concentrates on scenarios that require high checkpointing frequencies, which is often the case for automated error recovery techniques and debugging. We demonstrate the need for specialized high frequency memory checkpointing techniques and propose enhancements to current checkpointing techniques to make them fit for such use cases. Further, we explore the deployability trade-offs of different checkpointing techniques. We show that if the target application can be recompiled, pure userland techniques relying on compiler-instrumentation can offer a significantly better run-time performance than their page-granular counterparts without losing memory guarantees. Further, we show that speculation and exporting copy-on-write functionality as a first-level kernel primitive to the userland lowers the overhead of page granular checkpointing significantly. Finally, we examine techniques that can efficiently store and search the large amounts of checkpointed data resulting from the high checkpoint frequency. We then incorporate these techniques in Delorean, the first time traveling debugging system on top of high-frequency checkpointing. We hope that the techniques and tools developed in this thesis will facilitate the development of reliable software.

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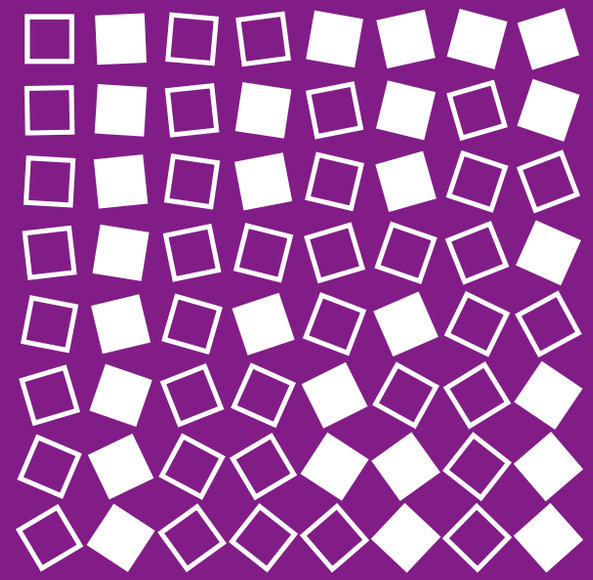

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